

## PEDESTRIAN PROTECTION BASED ON COMBINED SENSOR SYSTEMS

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### ABSTRACT

Pedestrian protection has come up to an important issue. The European Community (EC) has released a draft law, which mandates manufacturers to increase pedestrian safety. This law consists of two phases, beginning in 2005 and 2010 respectively.

To face up with present and future challenges, the Bosch roadmap of Electronic Pedestrian Protection (EPP) provides three sensor system generations: a contact sensor system (EPP1), a system combining contact sensors and ultrasonic sensors (EPP2) and a system combining ultrasonic sensors and video sensors (EPP3). In this paper, we focus on EPP2 and EPP3.

EPP2 uses synergy effects with ultrasonic systems (e.g. the parking aid) that are well-established on the market, in order to enhance the classification performance. In the EPP2 system, the ultrasonic sensor subsystem generates a feature vector which carries ultrasonic as well as geometric properties. This feature vector is combined with that of the contact sensor subsystem, which gives information about the mechanical object properties “stiffness” and “impact energy” of the object. The combination of the feature vectors leads to an improved and robust classification, allowing the use of an irreversible actuator.

In the EPP3 system, the video subsystem accomplishes pedestrian recognition in a mid-range ahead of the car and, if necessary, initiates a driver warning (acoustic, optical). Video-based pedestrian recognition is achieved by contour analysis, while tracking of pedestrians is carried out by applying an extended Kalman filter to active-shape representations of pedestrian contours. Any time the video subsystem predicts a pedestrian to enter the ultrasonic field-of-view, information concerning direction of movement and velocity of the respective pedestrian plus an estimate of the time-to-impact is

transferred from the video subsystem to the ultrasonic subsystem. The main task of the ultrasonic subsystem is to verify or reject the hypothesis of pedestrian presence delivered by the video subsystem.

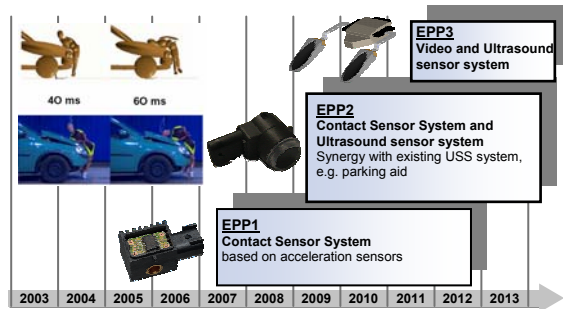
### INTRODUCTION

The year-2000 White Paper of the European Commission [1] states the target of halving the number of traffic fatalities on European roads until the year 2010. In November 2003, a European directive envisioning the protection of pedestrians and other vulnerable road users was passed [2]. This directive is made up of two phases becoming effective in 2005 and 2010 respectively. Models of new car platforms will then be type-approved only if they pass defined component tests with headform- and legform-impactors.

For several car types, the requirements can be fulfilled with passive solutions (e.g. energy-absorbing structures at a car’s front end). However, there are many models where active systems containing a sensing unit as well as an actuator element (e.g. an active hood – also called pop-up bonnet) are necessary.

Active protection systems based on contact sensors are able to fulfil the use-case tests that are defined by legislation. Nevertheless, the discrimination of use and misuse cases represents a challenge due to the real-world diversity of human beings and “misuse” objects (e.g. animals or pillars) occurring in the surroundings of road traffic. Even though this aspect is not encompassed by the EC directive, it is of prime importance with respect to customer satisfaction. Therefore, it is reasonable to think of systems containing remote-type sensors.

According to Figure 1, the Bosch roadmap of Electronic Pedestrian Protection (EPP) provides – besides the contact sensor system (EPP1), which



**Figure 1: Bosch Electronic Pedestrian Protection roadmap.**

will enter the market in 2007 – two further generations of interlocking sensor systems: a system combining contact sensors and ultrasonic sensors (EPP2) and a system combining ultrasonic sensors and video sensors (EPP3). In this paper, the focus lies on the latter two of these EPP system generations.

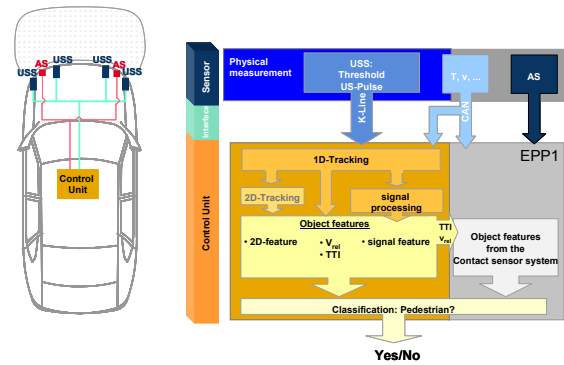
## ELECTR. PREDESTRIAN PROTECTION 2

### Motivation

Figure 2 shows a sketch of the EPP2 system. This system is composed of two subsystems: a contact sensor system (EPP1) and an ultrasound sensor system. In order to gain synergies by use of an existing ultrasound sensor system, the ultrasound sensors can also be used for e.g. a parking aid system.

The combination of the contact sensor system with an ultrasound sensor system leads to three main benefits:

- The object features obtained from the ultrasound sensor system are based on the reflection behaviour of the object and are thus in general independent from the mechanical object features “effective mass” and “stiffness” obtained by EPP1. These additional object features lead to an improvement of the object classification.
- The measured relative velocity  $v_{rel}$  is a beneficial information for the EPP1 algorithm: The use of the relative velocity instead of the vehicle velocity improves the estimation of the relative mass of the object.
- The estimated time-to-impact can be used for a faster safing functionality of the contact sensor system – in particular in the case of slow objects with a low acceleration signal.



**Figure 2: Sketch of the EPP2 system.**

### Contact Sensor Subsystem

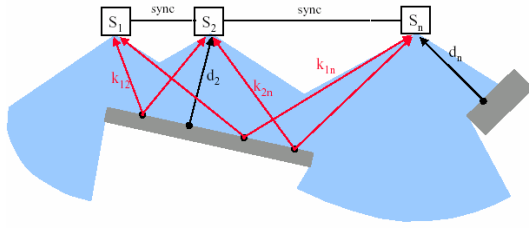
The contact sensor subsystem EPP1 is based on acceleration sensors, which are placed in the bumper cover. This allows to measure the object impact in a very early stage of the collision (within 10-15ms after the first contact). From the acceleration signals mechanical object features – the effective momentum as well as the object stiffness – are inferred. Additionally, EPP1 uses the velocity information of the vehicle in order to estimate the effective mass of the object from the effective momentum.

### Ultrasound Sensor Subsystem

In order to gain synergy with an existing ultrasound sensor system, we use standard Bosch generation-4 ultrasound sensors (USS4), which are in the market for e.g. the parking aid system. The sensors are located at the positions driven by the parking aid requirements. The USS4 provides a digital signal, which is obtained from the received analogue ultrasound echo by comparison with a threshold. The USS4 has a detection range of about 0.25m to 3m (related to a 7cm-tube).

The ultrasound sensors operate synchronized in parallel mode at which the time between two transmitted pulses is chosen stochastically. This so-called “stochastic coding” enables to use shorter cycle times down to 20ms even for large detection ranges and improves the robustness regarding external ultrasound systems [3]. Furthermore, the robustness regarding electromagnetic compatibility and ultrasound of other ultrasound systems is improved. Finally, this method allows to assign the received pulse to a transmitting and receiving sensor, i.e. to split-up the signal into direct and cross echoes for each sensor (see Figure 3).

The algorithm consists of three modules: a module for the estimation of the mechanical object features,



**Figure 3:** For a set of  $n$  ultrasound sensors  $s_1, \dots, s_n$ , direct echoes ( $d_1, d_n$ ) and cross echoes ( $k_{12}, k_{2n}, k_{3n}$ ) are measured. The stochastic coding enables an assignment of the measured echoes to a transmitting and receiving sensor, i.e. to a direct echo  $d_{ii}$  or cross echo  $k_{ij}$ .

a module for the estimation of the ultrasound object features, and a module for the fusion of both subsystems (see also Figure 2).

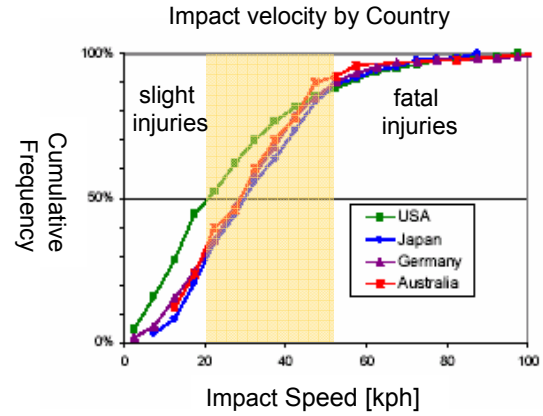
The module for the estimation of the mechanical object features is mainly given by the EPP1 algorithm. For a detailed discussion of the contact sensor system and the corresponding algorithm be referred to [4].

The module for the estimation of the ultrasound object features is based on tracking algorithms, in consideration of the stochastic coding, which provides a list of radial distances and velocities for each channel

The module for the estimation of the ultrasound object features is based on a stochastic coding algorithm which provides a list of one-dimensional object tracks for each channel, i.e., direct echoes  $d_{ii}$  and cross echoes  $k_{ij}$  (cf. Fig. 5). On basis of these object tracks ultrasonic object features as well as the variation of these features are estimated. Thus, for every object track a feature vector is obtained, which corresponds to the ultrasound properties of the concerning object.

The third module uses both the feature vector of the contact sensor subsystem and the feature vector of the ultrasound sensor subsystem. Using the estimated time-to-impact of the object, the ultrasound feature vector is assigned to the related impact feature vector. Based on these two feature vectors a classification of the object is performed.

Due to the fact that the one feature vector is correlated to the mechanical properties like stiffness and effective mass and the other feature vector is correlated to the ultrasound scattering behaviour – which is in general independent from

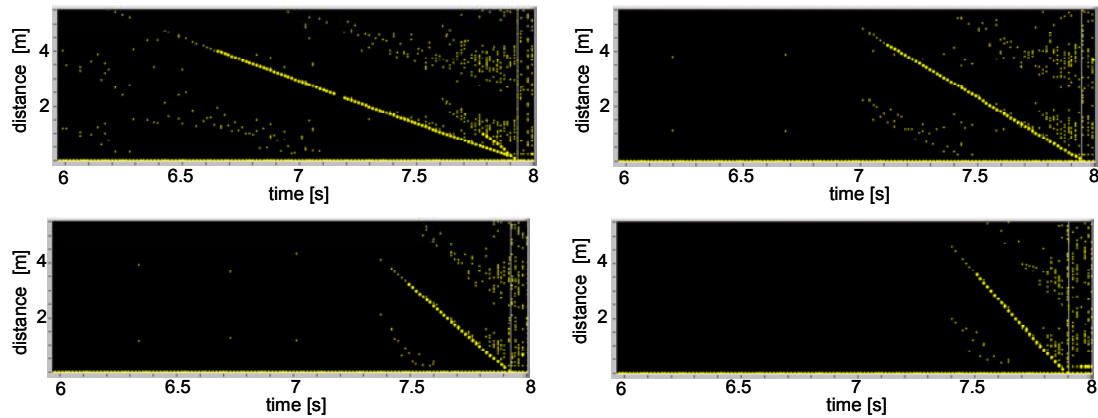


**Figure 4:** Cumulative frequency of accidents in dependency on impact speed. In the range of 20-50 kph (shaded area) most of all severe injuries occur.

system in order to calculate the effective mass from the measured effective momentum. This leads to an improved classification in cases where the velocity of the object is large and thus cannot be neglected by the calculation of the effective mass. The time-to-impact is needed in order to assign the right object track – and the right relative velocity – to the impact signal of the contact sensor subsystem. Moreover, the knowledge of the time-to-impact allows to reduce the thresholds of the safing path of the contact sensor algorithm. This leads to shorter decision times, in particular in cases where the object is slow and the signal as well as the safing signal is small.

#### Velocity range

EPP2 is designed for a velocity range of 20 – 50 kph. This velocity range is founded on statistical investigations, which show that at velocities lower than 20 kph slight injuries occur and an activation of protection systems is not necessary. For velocities faster than 50 kph, the impact energy is that large that an activated protection system does not significantly increase the chance of survival. Nevertheless, a velocity range of 20 – 50 kph covers a very large amount of accidents resulting in severe injuries (cf. Figure 4). In order to investigate the influence of the velocity on the performance of the ultrasonic system, collision tests with a test car and a cube at velocities from  $v = 10 - 40$  kph were performed. The results shown in Figure 5 demonstrate the functionality of the system in the required velocity range.



**Figure 5: Object tracks for velocities from 10kph (upper left) to 40kph (lower right). Even at 40 kph the cube was detected at 3.5 m and a stable object track was obtained. Note: for lower velocities the object was detected at a distance of 4 m.**

### ELECTR. PREDESTRIAN PROTECTION 3

#### Motivation

Stricter pedestrian protection requirements – as are currently under discussion for phase 2 of the EU legislation [1] – may necessitate to initiate an actuator deployment prior to the impact (e.g. the extended lifting of an active hood in order to provide sufficient deformation space between the deformable hood and non-deformable aggregates beneath it).

Video technology has a significantly longer detection range in comparison to stand-alone ultrasound systems and possesses a high potential with respect to the classification of pedestrians and other vulnerable road users [5,6]. Since video sensors for traffic applications are commonly mounted behind the front window, a video-based observation of entire pedestrian contours is feasible for distances greater than approximately 4 meters ahead of the front bumper. However, to have an enlarged detection range also covering small distances ahead of the car, a combined approach to pedestrian detection made up of video and ultrasound sensors is proposed.

#### System task

The task is to reliably detect impending collisions with pedestrians, to give a warning (acoustical, optical) and, if necessary, to trigger an actuator (e.g., an active hood) as early as possible before a contact of a pedestrian with the car front occurs.

#### Video subsystem

In our combined approach, video technology carries out the detection of objects, the classification of

detected objects with respect to the classes “pedestrian” and “non-pedestrian” as well as the tracking of pedestrians.

Video-based pedestrian detection and classification is achieved by contour analysis [7], while the tracking of pedestrians is carried out by applying an extended Kalman filter [8] to active shape representations of pedestrian contours [9].

Any time the video subsystem predicts a pedestrian to enter the ultrasonic field-of-view, information concerning direction of movement and velocity of the respective pedestrian plus an estimate of the time-to-impact is transferred from the video subsystem to the ultrasonic subsystem.

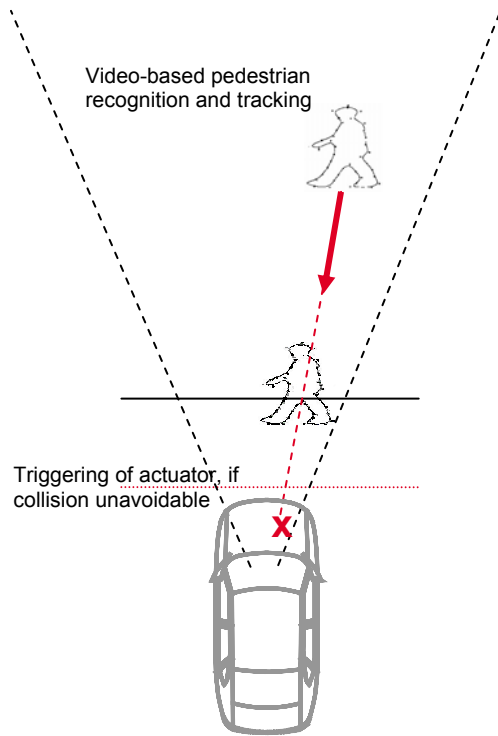
#### Ultrasound subsystem

The ultrasound subsystem provides for a verification of the pedestrian data received by the video subsystem. Moreover, it predicts collision parameters – in particular the time to impact, the closing velocity (i.e., the velocity of the pedestrian relative to that of the car at the beginning of the collision) – and triggers the actuator(s) – see Fig. 6.

#### System prototype

As shown in Figure 3, we have equipped a test vehicle with a stereo-video subsystem and a four-channel ultrasound subsystem.

The cameras of the video subsystem contain high-dynamic-range CMOS imagers with a resolution of 512x256 pixels. Video-based pedestrian recognition is accomplished in a range of up to 25 m ahead of the bumper at aperture angles of 50° horizontally and 35° vertically.



**Figure 6: Basic principle of electronic pedestrian protection using video and ultrasound sensors.**

Predictive information is transferred via CAN bus from the video subsystem to the ultrasonic subsystem. For details concerning the ultrasound system part, refer to the section above discussing the EPP2 system.

In comparison to EPP2, EPP3 provides a significant gain with respect to the forewarn time. According to our experiments, for a closing velocity of 30 kph, a final decision concerning the triggering of an actuator can be taken 150-200ms (i.e., 1-2m) before the actual beginning of a collision.

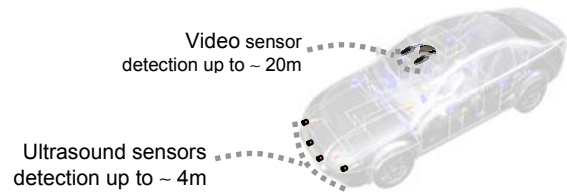
First preliminary test results confirm the feasibility of the chosen system approach. However, possible solutions regarding the handling of night-time situations, of partly occluded pedestrians and of groups of pedestrians have to be investigated in more detail.

#### Envisioned time of market introduction

Referring to the EPP roadmap in Figure 1, three key reasons can be given for a market introduction of EPP3 in the next decade:

##### a) *Legislation:*

Stricter protection criteria are to be expected in the European Union from quarter 4 of the year 2010 when phase 2 of the EC directive will become effective.



**Figure 7: Positioning of video and ultrasound sensors in the EPP3 prototype.**

##### b) *Technological and functional maturity:*

Video-based safety applications are yet to be introduced to the market. According to press announcements of several car manufacturers and suppliers, this will be done within the next five years.

##### c) *Price / Costs:*

Customers are price-sensitive. This is of particular importance for pedestrian protection systems, as these do not involve a direct benefit for the buyer and driver of a car. Price and cost degradation without sacrificing performance are expected to be sufficient in approximately five years. Synergies between safety and driver assistance will support the required degradation process.

## CONCLUSIONS

On the basis of system prototypes set up in test cars, we could demonstrate the feasibility of combined sensor systems for the task of electronic pedestrian protection.

By use of sensor system fusion, the pedestrian-recognition performance can be increased and plausibility can be guaranteed.

However, due to current technological limitations and complexity of real-world scenarios, it will take approximately three to five years until first system generations based on remote sensors appear on the market.

## REFERENCES

- [1] White Paper "European transport policy for 2010: time to decide", European Commission, 2000.
- [2] Directive 2003/102/EC of the European Parliament and of the Council, 11/2003.
- [3] B. Wirtzinger et al.: "Interference Cancellation in Ultrasonic Sensor Arrays by Stochastic Coding and

Adaptive Filtering”, IEEE International Conference on Intelligent Vehicles, 1998.

[4] U. Groeger et al.: “Active Pedestrian Protection – System Development”, Paper #04B-106, SAE World Congress, 2003.

[5] D. Gavrilă: “Sensor-based Pedestrian Protection”, IEEE Intelligent Systems, Vol. 16, No. 6, 2001.

[6] D. Gavrilă et al.: “Vision-based pedestrian detection: the PROTECTOR system”, Proc. IEEE Intelligent Vehicles Symposium, pp. 14-17, 2004.

[7] D. Gavrilă and J. Giebel: “Shape-based pedestrian detection and tracking”, Proc. IEEE Intelligent Vehicles Symposium, Vol. 1, pp. 8-14, 2002.

[8] G. Welch and G. Bishop: „An Introduction to the Kalman filter“, TR 95-041, Technical Report, Department of Computer Science, University of North Carolina, Chapel Hill, 2003.

[9] A. Blake and M. Isard, “Active Contours”, Springer, 1998.